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FM EMBEDDED ANTENNAS

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FM EMBEDDED ANTENNAS

by

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Report

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Invented in 1935, Frequency Modulation (FM) is one of the most widely used analog modulation techniques in telecommunications. Since its inception FM radio has been used for high-fidelity music and speech broadcasting, offering excellent sound quality, signal robustness and noise immunity. Recently, FM Radio has witnessed an explosion of interest for its applications in mobile and personal media players (PMP). However, the traditional FM requires a long antenna, such as a wired headphone, which limits its usefulness for many users who do not carry a wired headset. This paper introduces FM solutions that enable the antenna to be integrated or embedded inside the device enclosure, thereby optimizing the end solution for portable consumer electronics.

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Introduction

Frequency Modulation (FM) is a form of modulation which conveys information over a carrier wave by varying its frequency. For continuous-time input signals, the instantaneous frequency of the carrier is directly proportional to the instantaneous value of the input signal.

In most of the world, the FM broadcast band for radio stations is from 87.5MHz to 108MHz. Japan’s FM broadcast band is 76 to 90MHz. In some eastern European countries, the band is 65.8 to 74MHz.

The selection of an appropriate FM antenna is the most important aspect of receiving high quality FM broadcasts. This paper introduces optimum antenna structures for good reception. This is followed by a discussion of innovations in integrated antennas that make high quality FM reception possible with a fraction of the optimum antenna size.

Dipole and Monopole FM Antennas

Dipole Antenna

A dipole antenna is one that can be made by a simple wire with a center-feed-element. Typically a dipole antenna is formed by two quarter wavelength ($\lambda/4$) conductors placed back to back for a total length of $\lambda/2$. A standing wave on an element of length ~$\lambda/4$ yields the greatest voltage differential. One end of the element is a node while the other is an antinode of the wave. The larger the differential voltage, the greater the current between the elements.

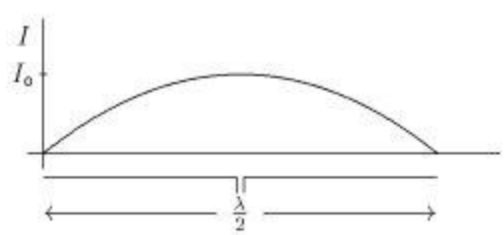

Figure 1 – Standing Wave centered at $\lambda/4$

The impedance of a dipole antenna is characterized by a real and an imaginary part. Figure 2 shows the dipole's impedance for lengths going from $0.4\ \lambda$ to $0.6\ \lambda$

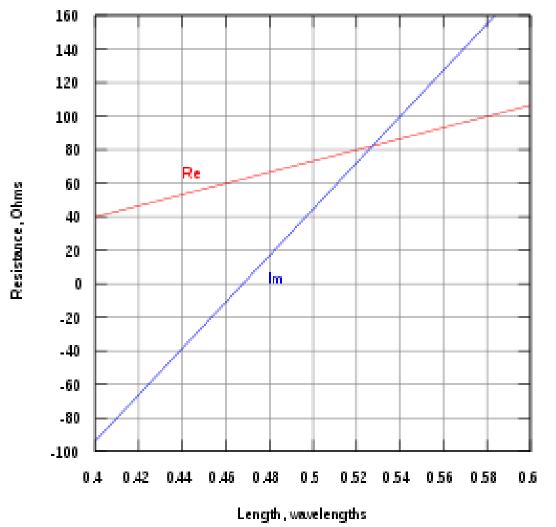

Figure 2- Dipole Antenna Impedance vs. Length

Dipoles have a toroidal (doughnut-shaped) reception and radiation pattern where the axis of the toroid passes through the center of the dipole.

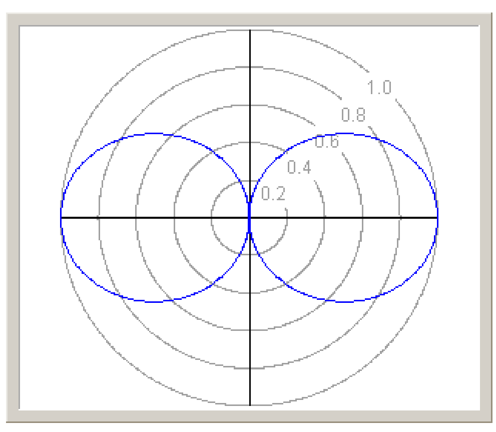

Figure 3- Half-Wave Dipole Radiation Pattern

The center of the FM frequency band is ~100MHz and the wavelength at this frequency is 3m. Hence, the half-wave dipole for maximal reception is 1.5m in length.

Monopole Antenna

A monopole antenna is a type of radio antenna formed by replacing one half of a dipole antenna with a ground plane at right-angles to the remaining half. A whip antenna is the most common example of a monopole antenna with a stiff but flexible wire mounted, vertically with one end adjacent to a ground plane.

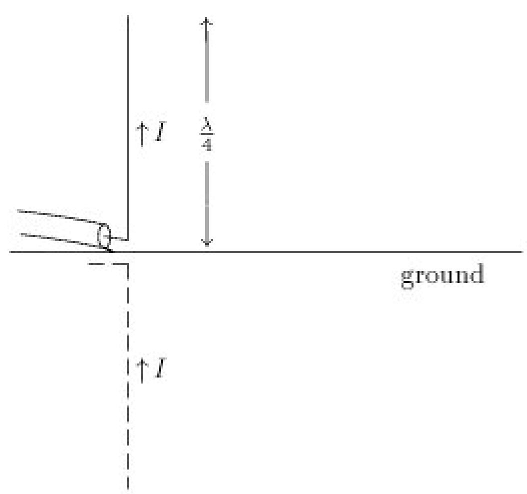

Figure 4 –Monopole Antenna

At FM Frequencies, an efficient whip antenna is ~750cm in length (smaller than a full-fledged dipole antenna but still has considerable length)

Embedded FM Antennas

In recent years FM receiver has become popular in handsets and other consumer electronics products. The compact size of portable devices has dictated the need for building FM antennas that are a fraction of the meter long length. This reduction in length affects the overall voltage generated on the antenna.

An important antenna characteristic is its radiation resistance (R). R is that part of the antenna's feed point resistance that is caused by the radiation of electromagnetic waves from the antenna. This resistance is determined by the geometry of the antenna and for a small (less than quarter wavelength) dipole antenna it is given by

$$R = 20\pi^2 \left(\frac{\ell}{\lambda}\right)^2 \qquad \textbf{1}$$

where ℓ is the length of the antenna in meters and λ is the wavelength of the signal in meters.

This implies that as the length of an antenna is halved, the radiation voltage is reduced to a quarter (-12dB). This is a significant loss in performance.

In addition to its radiation resistance R, an antenna has a reactive component – (inductive or capacitive) that is related to antenna geometry. Also, the output of the antenna generally drives the input of a low noise amplifier (LNA), which presents impedance

(Zload) to the antenna. The overall equivalent circuit is shown in Figure 5:

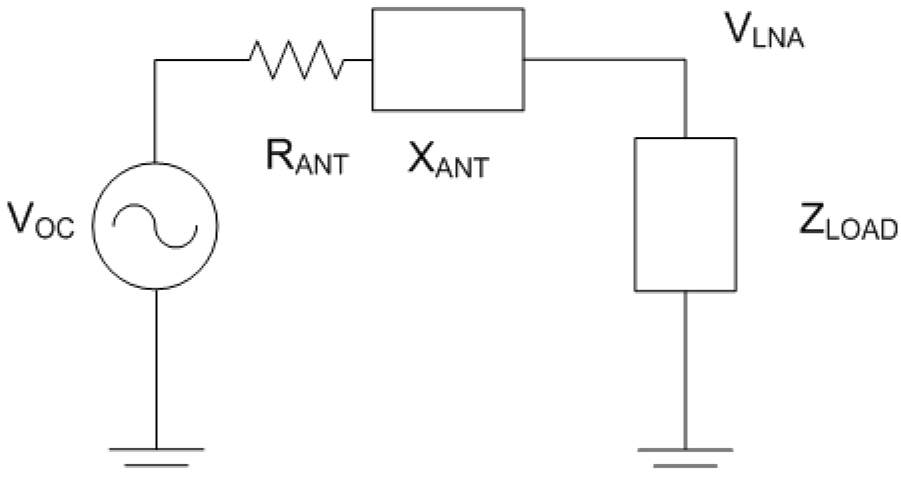

Figure 5 – Antenna Circuit Model

The open circuit voltage is limited by the size of the antenna. With a fixed input voltage, the key to maximizing the circuit performance is improving the SNR of the signal at the input of the LNA. This can be achieved by conjugate matching i.e. tuning the antenna at the frequency of interest. Since the FM frequency band is 40 MHz wide the resonance would need to be retuned based on the desired channel.

Tunable Antenna Resonance

An ideal parallel LC circuit has infinite impedance. FM antenna structures (optimum length or significantly shorter than quarter wavelength) can be modeled with a resistive component and a reactive component (inductance or capacitance based on the type of antenna). The reactive component of this model can be resonated with conjugate matching at the input of the LNA. Additionally, the load impedance can be further controlled with an on-chip tunable varactor (also called tuned capacitor) at the input of the LNA. This would allow fine tuning the antenna circuit resonance at the FM frequency of interest.

In practical applications, the resonated impedance is limited by the quality factor (Q) of the reactive components. Inductor Q is limited to about 30 and capacitor Q is usually about 50. Figure 6 shows a reasonable estimate of load impedance based on nominal capacitive antenna terminated with a shunt inductor.

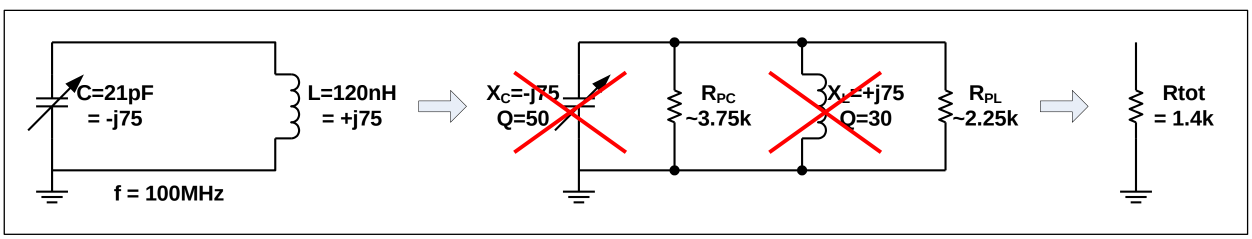

Figure 6 – Resonant Antenna Impedance

$$R_P = Q.X$$

$$R_{PC} = 3.75k$$ 21pF capacitance, Q of 50

$$R_{PL} = 2.25k$$ 120nH inductance, Q of 30

$$R_{tot} = \frac{R_{PC} R_{PL}}{R_{PC} + R_{PL}} = \frac{3.75k * 2.25k}{3.75k + 2.25k} = 1.4k$$

At 100MHz with actual components

The overall Q of this system is about 20. This also implies that the open circuit voltage received at the antenna can be gained up significantly at the LNA input because the circuit is resonated. Figure 7 compares the gain of a high Q resonated embedded antenna system to a FM monopole (headphone) antenna.

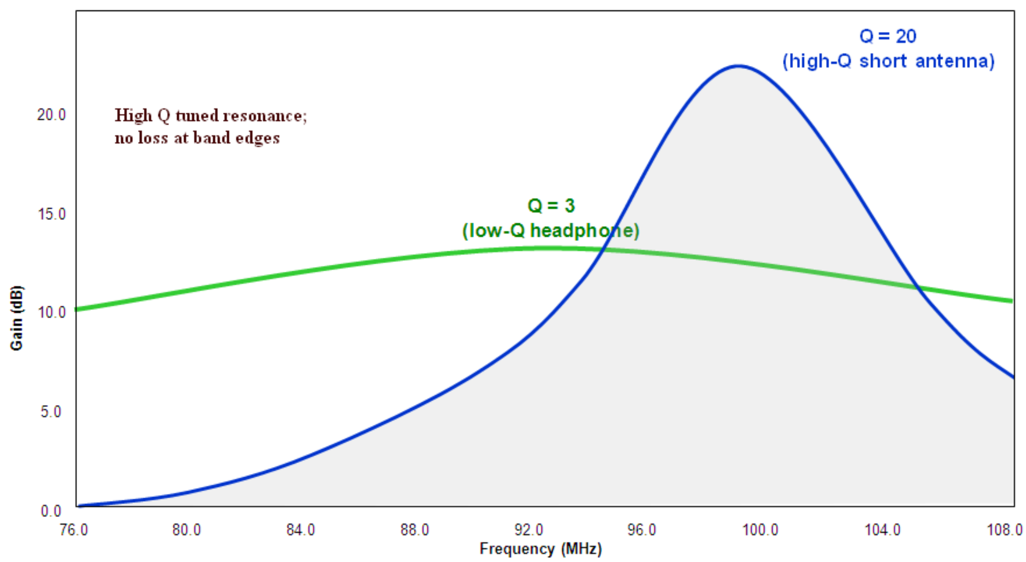

Figure 7 – Headphone and Embedded Antenna Resonance

The headphone antenna is also resonated with a shunt inductor in circuit but has a low Q resonance to avoid signal loss at band edges. The retuning of the embedded antenna circuit eliminates the voltage reduction at the edges of the FM band[1].

1 The concept of tuned resonance cannot be ported to headphone antennas because their impedance varies significantly with orientation. The details of this discussion are beyond the scope of this paper.

Tuned Antenna Implementations

Integrated FM antennas can be broadly classified into two categories – stub antennas and loop antennas.

Stub Antennas

Stub antennas have a single connection point on the circuit at the input to the LNA. The reactive component of these antennas is capacitive. These can be made from either of loose wire, flex printed circuit (FPC), PCB trace or electroplated plastic. Some reference shapes are shown in figure 8.

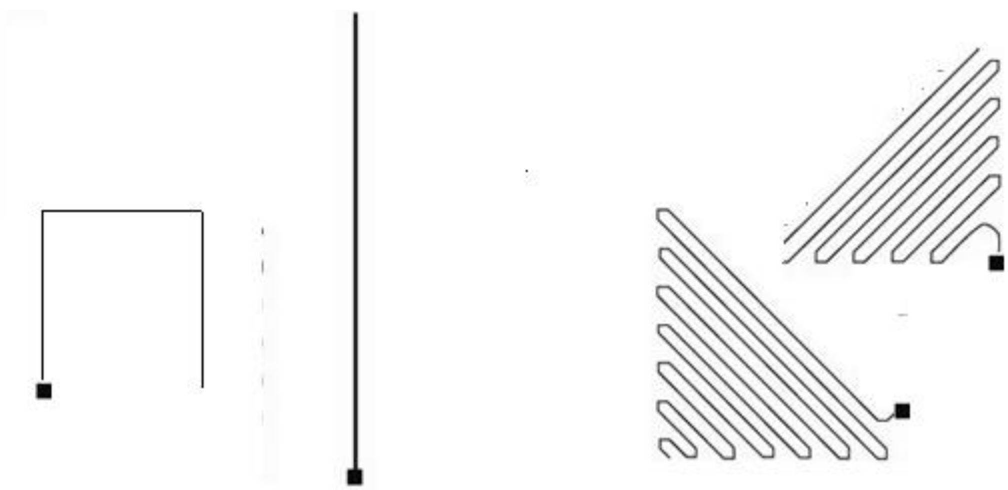

Figure 8 – Stub Antenna

The capacitance of the antenna depends on its effective length, orientation and proximity to the ground plane within the device, Some lab implementations of the stub antenna are shown below.

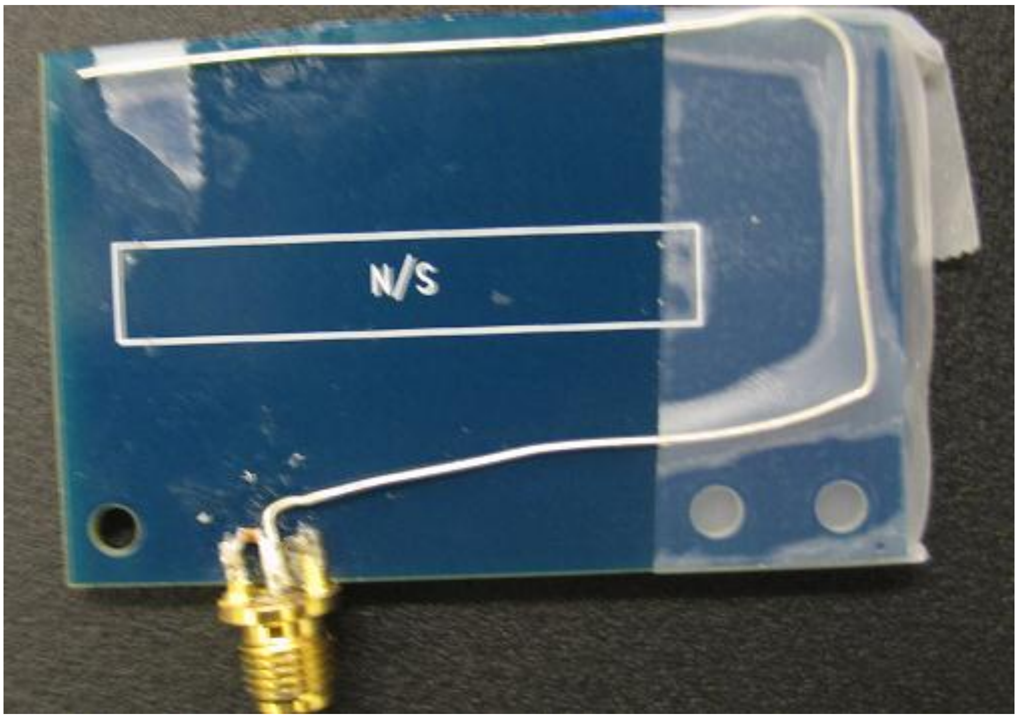

Figure 8 – 10 cm U shaped stub antenna (Effective length = 10cm)

Figure 9 – Stub antenna designed to maximize the amount of wire within a given space

(Effective length is the perimeter of the board ~16cm)

The impedance of the antennas shown above was measured with a Vector Network Analyzer. The capacitance of these antennas was found to be between 2 and 5pF. A 120nH shunt inductor was used to resonate the antennas within the FM band. A Si4705 FM tuner with a varactor at the LNA input was used to test the tuned resonance. The results were compared to a reference 1m headphone antenna. The embedded antenna with tuned resonance performed about 10dB worse than the headphone over the US FM band.

This is a significant improvement since without the tuned resonance, a 15 cm antenna would perform about 30dB worse than the headphone antenna (*refer to equation 1 above for radiation resistance*).

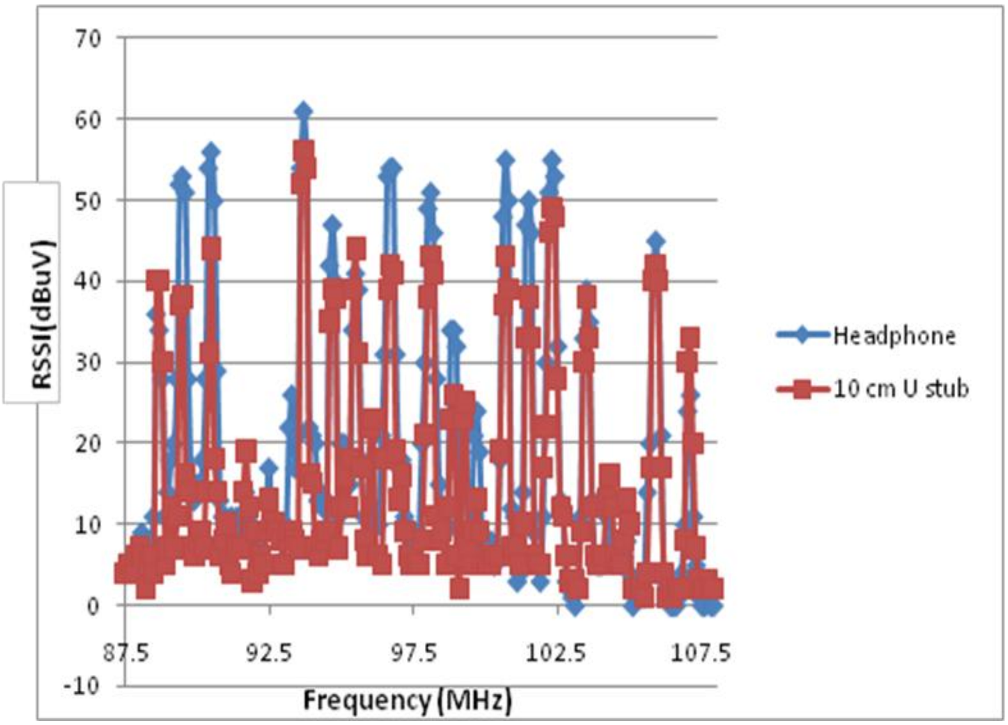

Figure 10 – Received Signal Strength Indicator (RSSI) vs. Frequency of Stub & Headphone Antenna

Loop Antennas

Loop Antennas have two connection points on the circuit – one to the LNA input and the other to RF ground. The reactive component of these antennas is inductive. These antennas can also be made with loose wire, FPCs, PCB trace etc,

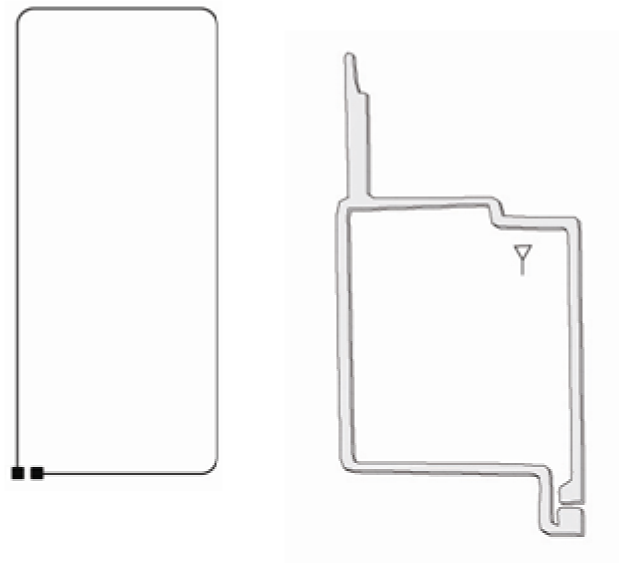

Figure 11 – Loop Antenna

The inductance of the antenna depends on area of the loop, loop radius, number of turns and proximity to the ground plane. Lab implementation of the loop antenna is shown in figure 12 below

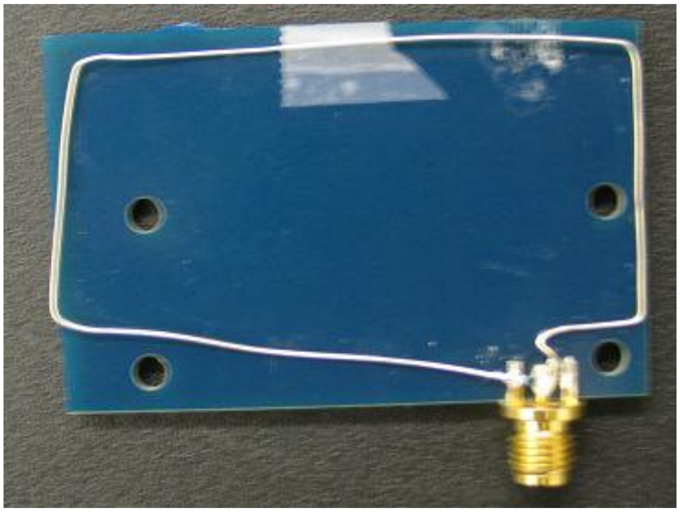

Figure 12 – Loop Antenna; Perimeter 14cm

The measured antenna inductance was 120nH. This antenna was directly connected to the Si4705 LNA input (with tunable varactor). Received signal strength of this antenna compared to a 1m headphone antenna was found to be about 13dB worse over the US FM band.

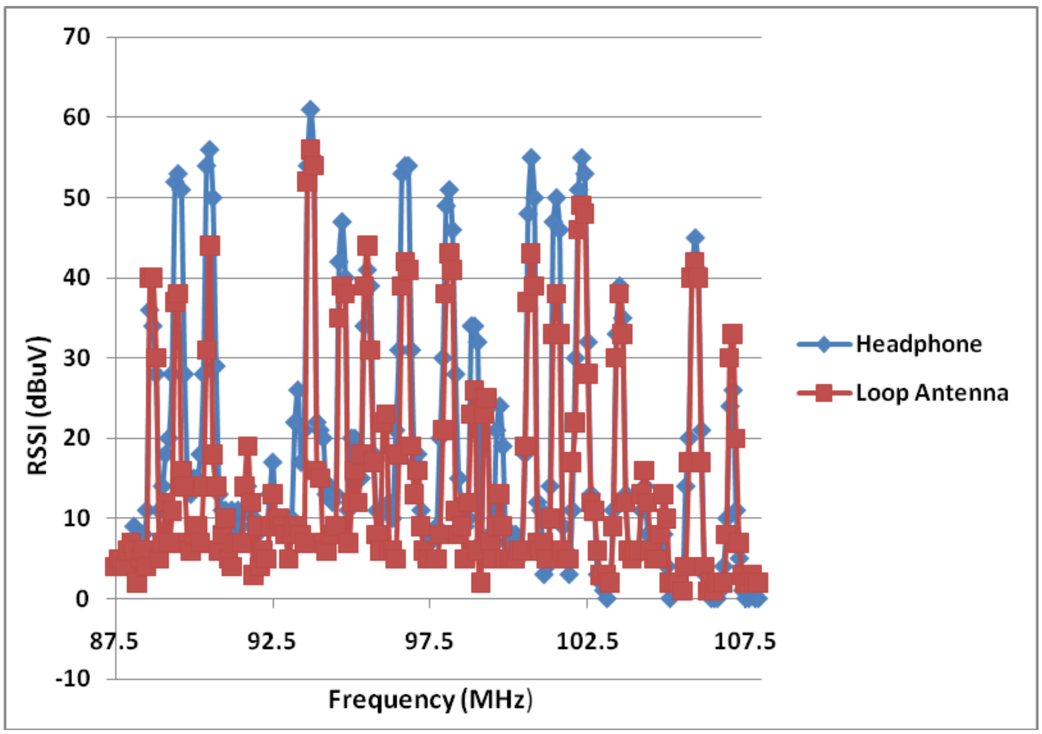

Figure 13 – RSSI vs. Frequency of Loop and Headphone Antenna

Conclusion

Wireless usage models are becoming more popular in portable devices eliminating the optimum headphone antenna required for FM reception. Given this trend, the consumer electronics industry is gearing towards embedded FM antennas, which are usually a fraction of half wavelength. This paper discussed maximizing the performance of these antennas using tuned resonance. Both antenna theory and lab experiments prove that received signal strength of an embedded antenna can be significantly improved (up to 20dB) by using this technique.

References

http://www.eetindia.co.in/STATIC/PDF/200902/EEIOL_2009FEB16_RFD_TA_01.pdf?SOURCES=DOWNLOAD

http://www.silabs.com/Marcom%20Documents/Resources/Si471x_Presentation.pdf

http://en.wikipedia.org/wiki/FM_broadcasting

http://en.wikipedia.org/wiki/FM_broadcast_band

http://en.wikipedia.org/wiki/Dipole_antenna

http://www2.electronicproducts.com/Internal_FM_antenna_strips_reception_duties_from_headset_cords-article-hlrr01-jun2007-html.aspx

http://www.kyes.com/antenna/dipole.html